Renewable and Sustainable Energy Reviews 15 (2011) 3237–3242

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Zero net house: Preliminary assessment of suitability for Alberta

Ghassan A. Zabaneh*

Harvard University Extension School, 51 Brattle Street, Cambridge, MA 02138-3722, United States

ARTICLE INFO

Article history:
Received 10 December 2010
Accepted 6 April 2011

Keywords:
Zero net house
Sustainable house
Alberta
Energy efficiency

ABSTRACT

The author examines the zero net house (ZNH) concept and makes preliminary assessments of suitability for Alberta. The aim is to improve energy efficiency and reduce green house gas (GHG) emissions. The author compares a theoretical ZNH model, constructed from available historical data; construction data; and trends of consumption in Alberta to models of average class house (ACH) and industry-endorsed technical performance standard (R-2000). Results indicate that ZNH is capable of achieving more GHG reduction levels and reduces energy requirements of occupants compared to ACH and R-2000. Construction costs of ZNH in Alberta exceed that of ACH by 15% but falls within literature's range. With energy escalation rate of 15% per year, the ZNH savings could potentially allow occupants to pay off a significant part of the ZNH.

Contents

1. Introduction

As global warming effects on our environment intensify, there is urgency among many to advance mitigation from the domain of volunteerism into the realm of policy and regulation. On a global scale, buildings will contribute a third of green house gases (GHG) by 2030 [1,2]. Half of this energy is used for space heating/cooling; the other half is consumed as electricity [3,4]. Approximately 85% of this energy is generated from fossil fuels. The potential reduction of energy expenditure and emissions through efficiency is therefore significant [2]. GHG levels coupled with increasing cost of fossil fuels are making efficiency concepts, such as zero net housing (ZNH), attractive. ZNH is a designation awarded to a dwelling that is capable of producing similar amount of energy as it consume over a period of 1 year [5].

Transitioning housing to environmental efficiency in Alberta is complicated by sever climate and reliance of the government on oil extraction royalties for generating income (Government of Alberta 2009, [6]). As the limited oil reserves diminish, increased reliance on dirtier resources such as the oil sands, to meet energy and revenue needs, Alberta's environment is becoming increasingly

* Correspondence address: 8515 106A Street NW, Edmonton, Alberta, Canada T6E 2E6. Tel.: +1 780 439 7640; fax: +1 780 492 6353.
E-mail address: gzabaneh@ualberta.ca

1364-0321/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2011.04.021

polluted and the government is failing to fulfill its commitment to reduce GHG.

To correct this unsustainable course, the author invites the government to seriously consider energy efficiency in the residential sector to save valuable resources by enforcing reasonable environmental regulation. Citizens of Alberta would benefit most by reducing their reliance on fossil fuels; save money by conserving energy; maintaining levels of comfort they expect from their homes; and reduce environmental impact on future generations.

To advance this view, the author will examine the ZNH concept and consider its suitability for Alberta. The author will make a preliminary assessment to the effectiveness of ZNH measures in reducing GHG emissions and if measures reduce reliance on fossil fuel. The author will use an average class house (ACH) built in Alberta as a baseline to compare the efficiencies of industry adopted environmental standard for residential construction (R-2000) and ZNH.

2. Previous studies

In 2006, there were approximately 1,335,745 dwellings in Alberta with a population of 2.5 per dwelling [3]. Construction industry contributions to the GDP in Alberta grew by 63% between 1997 and 2006, resulting in an increased destructive impact on the environment [3]. Meanwhile, other governments were legislating GHG reduction measures for buildings. The government of New York City, for example, requires buildings above 5000 ft^2 to submit energy audits and mandate actions to reduce energy consumption [4]. Britain also has set a target for all new houses to be net-zero carbon by 2016 [7]. Several provinces in Canada have been taking steps to encourage more efficient buildings. British Colombia and Manitoba have implemented measures to upgrade energy efficiency requirements in building codes, and many building codes within Canada are moving towards emphasis on efficiency but most measures are voluntary, such as the R-2000 certification [8,9].

Moomaw, discussing the results of his NZH experimentation, has indicated that the house is capable of energy savings of 84% compared with a house built to Massachusetts code. He also indicated that electrical needs could be met by a solar panels array producing 7 kWh/day on average. Most importantly, the Moomaw ZNH construction expenditure was an additional 10% above average cost.

A study conducted in 2006 collected and compared data from two identically sized houses in Las Vegas, Nevada. It established that it is indeed possible to reduce the yearly energy use to near zero by implementing good design methods and alternative energy sources [5].

A cost-benefit study conducted in 2006, on a net-zero energy residence house at the University of Dayton, Ohio, concluded that the design implemented was able to deliver a zero net energy usage. That specific design, while managing to offset energy costs and emission, will take 35 years to recover construction costs because of electricity bill payment mechanisms.

A case study for affordable ZNH assessed its suitability for cold climates. The U.S. Department of Energy supported study examined a 1200 ft^2 house in Denver, Colorado. It aimed to optimize solutions to move design towards a simplified, easily maintained system with friendly construction techniques. The house included an efficient envelope, appliances and lighting, and passive and active solar features [10]. The house used the solar array to offset dependence on natural gas for heating. Results showed that the house surpassed its goal of zero net and produced 24% more energy than it needed. It also found that sizing a PV system is difficult with predictions of energy use being reliant on the behavior of occupants. Economic return from selling excess energy was dependent on net metering agreements and did not result in a zero utility bill because of fixed costs. The study determined it was possible to build a ZNH from off-the-shelve material [10].

Table 1
Summary of values used to determine consumption levels.

Daytime average temperature in Canadian homes (°C)	20–22
Nighttime average temperature in Canadian homes (°C)	16–18
Average electrical usage in Alberta homes (kWh/m)	600
Average natural gas usage in Alberta homes (GJ/m)	11

The literature reviewed here leans towards suggesting, with mixed results, that a ZNH is capable of delivering financial and environmental benefits. Research conducted in this area appears to lag behind other research into building efficiency such as LEED[1] [11]. Most researchers, such as Norton and Christensen, admit that the success of ZNH designation ultimately relies on the habits of the occupants; however, the author found no studies that outlined the characteristics of such occupants and divergence levels from the average. There were no long-term studies that considered the structure and occupants within it that collected data on more than two houses. This area of research could benefit from large-scale studies with a social and psychological focus.

3. Data collection program

The baseline model is an average construction house derived from reviewed literature and Albertan averages. The cost of construction of an ACH is \$101 USD/ft^2 (R.S. [12]). Values of consumption for the ACH are summarized below Table 1.

3.1. Common features between house models

The basic model is designed from standard plans. It is a two story detached house with a fully developed basement built in 2009.[2] Living area is equal to 2000 ft^2 with1500 ft^2 heated ([9], p. 53). It has windows distributed equally in all cardinal directions. The unit's four occupants need an average of 600 kWh/m of electricity and 11 GJ/m of natural gas to maintain average temperature of 22 °C [13,14].

3.2. Average class house

The ACH represents the average contemporary house in Alberta with no consideration to passive solar orientation. It meets energy performance requirements of Alberta building code (see Table 2). It cost an average of \$101.83 USD/ft^2 (price adjusted for region) (R.S. [12]). It has R12 insulation in the walls and R34 in the attic. The ACH connects to the grid to meet energy needs. The cost of the ACH unit is about \$203,660 USD (R.S. [12]).

3.3. The R-2000 house

This model is built according to industry-endorsed technical performance standard for indoor air tightness quality and energy efficiency. The R-2000 standard is voluntary [15]. The stated energy efficiency, at a minimum, is 30% above that of the ACH [16]. Similar to the ACH, the R-2000 connects to the grid for energy supplies. To achieve certification level, the R-2000 house utilizes innovative technologies and construction techniques, such as better grades of insulation, Energy Star certified appliances and a heat recovery

[1] Greening buildings has been proven financially beneficial and analysis of returns on LEED certified building ranges between \$48 and 67 USD/ft^2.

[2] Detached houses constitute about 60% of all residences in Alberta (Natural Resources Canada (NRCan, 2007, p.13).

Table 2
Thermal insulation requirements for small buildings from the Alberta Building Code (AEEA 2009).

Location of assembly in which insulation is placed		Minimum thermal resistance	
		RSI	*R*-value
Wall assembly (except basements)	Building exterior 2.1		12
	Between building and attached garage	2.1	12
	Exterior of heated garage	2.1	12
Basement and crawl space	Perimeter walls (top to 600 mm below grade)	1.4	8
Floor assembly	Perimeter	2.1	12
	Exposed cantilevers	3.5	20
Roof-ceiling assembly	Building-general	0.6	34
	Heated garage	0.6	34

Table 3
Summary of key characteristics between houses compared.

Item	ACH	R-2000	ZNH
Walls cost ($USD)	100%[a]	107%[c]	107%[c]
Windows cost ($USD)	100%[a]	192%[c]	192%[c]
Ceiling cost ($USD)	100%[a]	105%[c]	105%[c]
Walls insulation (R)	12[b]	39[c]	39[c]
Windows insulation (R)	2[b]	5[c]	5[c]
Perimeter insulation (R)	18[b]	23[c]	23[c]
Roof insulation (R)	34[b]	49[c]	49[c]
Infiltration (ACH) Air changes/hr	0.62[c]	0.35[c]	0.35[c]
Programmable thermostat used	Yes[d]	Yes[d]	Yes[d]
Daytime temperature (°C)	20–22[d]	20–22[d]	20–22[d]
Nighttime temperature (°C)	16–18[d]	16–18[d]	16–18[d]
Connected to natural gas grid	Yes	Yes	None
Furnace efficiency	80%[c]	80%[c]	None
Air Conditioning (COP)	10[c]	10[c]	None
SEER heat pump	None	None	14.5[c]
Heat recovery Ventilator	None	Yes	Yes
Photovoltaic array	None	None	Yes
Connected to electrical grid	Yes	Yes	Yes

[a] R.S. Means 2006.
[b] AEEA 2009.
[c] [30].
[d] [13].

ventilator (see Table 3). Additional cost for R-2000 certified house is about 5% above the ACH [17].

3.4. The zero net house

To qualify as ZNH, a house needs to conserve energy as well as produce it with a net-zero energy consumption and net-zero carbon emissions over 1 year. The model used here is similar to R-2000 with three major exceptions:

1. The house uses Larsen trusses to achieve higher insulation value [10,4].
2. It is not connected to the natural gas grid; occupants rely on a geothermal system installed on site to meet their heating needs.
3. Electrical consumption from the grid will be zero or a negative value; electrical power will be supplied from a photovoltaic array (PV) installed on site.

3.5. Comparison of techniques/technologies used in the houses

1. *Envelop insulation:* The ACH meets building code insulation level. Meanwhile the envelope for the R-2000 and ZNH meet the minimum 30% additional efficiency required by R-2000 specifications.
2. *Heat recovery ventilator (HRV):* The ACH lacks a HRV but it is required by the R-2000 and ZNH specifications. The model considered here is a Fantech SHR3005R SHR Series, with 247 ft^3/min, and apparent sensible effectiveness of 91% at −25 °C [18]. It costs $1420 USD [19].
3. *Direct exchange geothermal system (DX):* Installed only for the ZNH, this flexible and highly effective system is significant in achieving a net-zero designation [20,21]. The system can be used for heating and cooling. It cost about $6 USD/$ft^2$ for an estimated 3 ton of capacity [22].
4. *PV array:* Installed only for the ZNH, the model used is Kyocera KD210; Solectria inverter; and a grid tie solar power system WSS Select 4620 [23]. It will provide an estimated 693 kWh/month based on an average of 5 h of sun per day [24]. The system is advertized as virtually maintenance free with a life expectancy of +30 years. It costs about $8.39 USD/$ft^2$ based on installation estimations [25].

Since the ZNH electrical system is connected to the grid, the electricity fed into the grid will be credited and will cover future bills. However, Rafflo demonstrated that there is cost associated with the connection beyond electrical consumption. Bills include cost of generation, distribution and tax surcharge (2006). As a result, the PV feed into the grid achieved savings but generated no income. The Alberta ZNH PV system will, most likely, produce similar results. The author thus will not include the electric generation surplus in his calculations because of estimation difficulties.

4. Discussion and results

The production and consumption of energy is central to economic activity. The residential sector current energy requirement is one fifth of overall energy consumption in Canada. Since the 1980s, Alberta primary energy consumption increased three folds to 3,375,571TG. The IPCC 2007 report indicated that “efficiency options for new and existing buildings could considerably reduce CO2 emissions with net economic benefit (high agreement, much evidence)” (IPCC 2007). The good news is that GHG was reduced by 23% to 41,719 kton between 1996 and 2002 [3] due to technical innovation and building code upgrades (see Fig. 1). However, from 1990 to 2002 electric use in Alberta increased 23% to 60,120 mton h.[3]

4.1. Suitability of geothermal and solar system for Alberta

Typical PV cells have an efficiency rating between 10 and 20%. The Kyocera KD210 positioned at 54°24′N latitude, the average power delivery is approximately 32.1 kWh/day,[4] using an esti-

[3] About 60% of electricity was produced by hydropower; 16% nuclear; and most of the remainder with fossil fuel [3].
[4] Estimation based on information from Wholesale Solar [23].

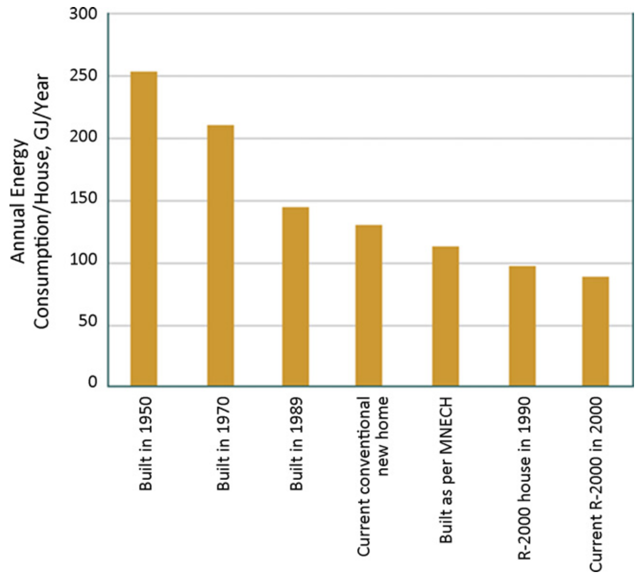


Fig. 1. Energy savings rates [14].

mated 518 ft^2 array ([26], p. 42).[5] Alberta has an average of 312 sunny days per year [24] with an average solar insulation of 3.37 kWh/m^2/year (0.312/ft^2). These averages are considered suitable for generating electricity using PV arrays [27].

As for geothermal energy, maps of shallow depth temperature demonstrate great variability across Canada with Southern Alberta boasting great potential. Calculations of potential geothermal energy available for extraction, is vast with an estimated value of 1.1 E21J (1100 quads) [28]. The western platform is particularly large with reserve estimations that dwarf the thermal equivalent of all Canadian fossil fuel reserves. The utilization of such a resource should present a great opportunity to reduce CO_2 across Canada [29].

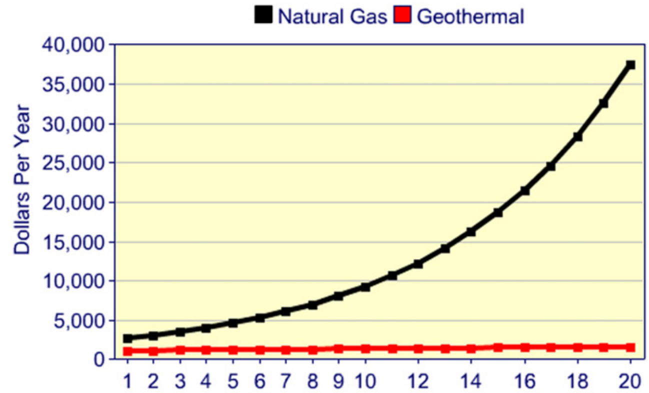
4.2. Preliminary assessment of economic return

After examining and performing simple calculations, based on data collected and summarized in Table 4, the author observed the following:

Calculations indicate a 5% additional cost of construction for R-2000 house and 15% for ZNH compared with ACH. The Moomaw house incurred an additional 10% cost (2010), while Rafflo's incurred an additional 20% (2006). The cost estimation for a ZNH in Alberta is arguably reasonable and falls within the range indicated by previous studies.

The total energy expenditure for the ACH is 146GJ/year; the R-2000, 102 GJ; and near zero for ZNH. Moomaw and Rafflo indicated similar results; the Rafflo house relied mainly on PV array for generation of energy. Tariffs imposed by the utility and the tax surcharge incurred a charge of $29 USD/year [30]. Meanwhile, the ZNH, and Moomaw house, incorporate the use of geothermal system. In both cases the heat pump uses electricity generated from the PV array, eliminating any operational expense. The ZNH model proposed by the author is able to save almost the amount expense of ACH's natural gas expenditure ($1511 USD/year)—two-thirds of overall energy consumed by ACH. Choosing geothermal for heating/cooling appears to accomplish a better return on investment when compared with the strictly solar option Rafflo investigated.

[5] Cambridge shire, UK is similarly positioned at 52°12′N.



Year	Savings	Total Savings
1	$1,513.00	$1,513.00
2	$1,885.29	$3,398.29
3	$2,316.33	$5,714.62
4	$2,814.99	$8,529.61
5	$3,391.48	$11,921.09
6	$4,057.52	$15,978.61
7	$4,826.61	$20,805.22
8	$5,714.28	$26,519.50
9	$6,738.37	$33,257.87
10	$7,919.42	$41,177.29
11	$9,281.02	$50,458.31
12	$10,850.35	$61,308.66
13	$12,658.62	$73,967.28
14	$14,741.73	$88,709.01
15	$17,141.00	$105,850.01
16	$19,903.93	$125,753.94
17	$23,085.13	$148,839.07
18	$26,747.42	$175,586.49
19	$30,963.04	$206,549.53
20	$35,815.08	$242,364.61

Fig. 2. Estimation of financial return on energy savings. (Geothermal Cost Estimator, ND).

All net-zero houses seem to create financial benefits; however, it appears that with careful design some are able to offer a better return on investment than others. Rafflo predicts that it will take 35 years for investors to recover the cost of student residence through energy savings in Ohio. In Alberta, the historical price escalation rate for natural gas between 1999 and 2008 was approximately 40%—the recession year of 2009 was excluded [31]. Using a more conservative escalation rate of 15% per year for future natural gas prices, a simple financial estimation of return for the ZNH (see Fig. 2) indicates that it will take an investor about 20 years to recover the entire cost of construction and 9 years for the 15% additional cost of the ZNH—solely from savings on natural gas consumption.

4.3. Preliminary assessment of environmental impact of ZNH

The average energy use of a typical ACH house is equal to 196 GJ/year. This amount is equivalent to 4378 l of gasoline (1157 gal) [32] and produces annual CO_2 emissions of 10.3 mton. It would require 264 trees over 10 years to offset this amount of CO_2. There were 23,000 housing starts in Alberta in 2009, a decline from previous years. A simple calculation based on the example above would indicate that the average CO_2 emitted from these new houses is about 236,900 mton. It would require about 50,512 acres of pine or fir forests a year to offset this amount of emissions. Offsetting this amount of CO_2 is equivalent to reducing the seven coal-fired power plants operating within Alberta by 3.72% (Clean Energy, 2010) (Table 5).

Table 4
Comparison of costs between examined houses.

Item	For the entire house			Per square foot		
	ACH	R-2000	ZNH	ACH	R-2000	ZNH
Base cost of structure	$203,660[a]	$203,660	$203,660	$101.83	$101.83	$101.83
Furnace	Included[b]	Included	−$8559[c]	Included	Included	−$4.28
Air conditioner	Included	Included	See note[d]	Included	Included	None
Heat/cool pump	NA[e]	NA	$12,000[f]	NA	NA	$6.00
Heat recovery ventilator	NA	$1420[g]	$1420	NA	$0.71	$0.71
Additional 30% insulation efficiency	NA	$10,183[h]	$10,183	NA	$5.09	$5.09
Electrical grid connection	Included	Included	Included	Included	Included	Included
PV array system	Included	Included	$16,780[i]	Included	Included	$8.39
Total	$203,660	$215,263	235,484.00	$101.83	$107.63	$117.74

[a] Estimation is based on R.S. Means, and adjusted for Alberta (R.S. [12]).
[b] Indicates item price was included in the base cost of structure.
[c] Not required for ZNH and cost is removed from estimation (R.S. [12]).
[d] The furnace (heating and cooling system) provided by R.S. Means includes the price of air conditioning (R.S. [12]).
[e] Not applicable.
[f] Based on estimations from the U.S. Department of Energy: Energy Efficiency & Renewable Energy (U.S. Department of Energy 2008).
[g] Fantech SHR3005R SHR Series, with 247 ft^3/min, and apparent sensible effectiveness of 91% at −25 °C ([18], Fantec 2010).
[h] Based on information from the Government of Canada: Sector Sustainability Tables [16].
[i] A grid tie solar power system based on estimation provided by Wholesale Solar [25].

Table 5
Comparison of Energy expenditure between examined houses.

	For the entire house			Per square foot		
	ACH	R-2000	ZNH	ACH	R-2000	ZNH
Cost of construction ($USD)	203,660	215,260[a]	235,060[b]	101.83	107.63	117.53
Electrical use (kWh/year)	7200	5040[c]	5040[12]	3.6	2.52	2.52
Electrical use (kWh/year) from the grid	7200	5040	0	3.6	2.52	0
Electrical use cost ($USD/year)	454	318	0	0.23	0.16	0
Natural gas (GJ/year)	130	91[12]	0	0.065	0.046	0
Natural gas cost ($USD/year)	1511	1057[12]	0	0.76	0.53	0
Electricity & gas cost ($USD/year)	1964.24	1374.97	0	0.98	0.69	0
Electrical & gas in (GJ/year)	145.92	102.144	0	0.073	0.051	0

[a] Additional cost of 5% based on Natural Resources Canada information (NRCan 2010).
[b] Additional cost of 15% based on calculation demonstrated in Table 4.
[c] At 30% efficiency based on Natural Resources Canada information (NRCan 2010).

5. Conclusions

The author examined the ZNH concept and made preliminary assessments for the suitability of its application in Alberta and its ability in minimizing GHG emissions by reducing reliance on fossil fuel. Based on literature review and a preliminary assessment between ACH, R-200 and ZNH, the author concludes the following:

1. Only a small body of literature examines ZNH, more extensive large-scale research is required within Alberta to determine the benefits and challenges more accurately.
2. The existing body of literature leans towards agreeing, with mixed results, that building ZNH is capable of delivering financial and environmental returns.
3. Solar insolation values in Alberta are considered suitable for generating electricity sufficient to meet typical demand using PV arrays.
4. Southern Alberta boasts a great potential for geothermal energy with reserves estimations that dwarf all Canadian fossil fuel reserves.
5. A ZNH house costs approximately 15% more than the ACH house. This extra cost falls within the range indicated by reviewed literature. This additional cost is redeemable through savings generated from the elimination of natural gas expenses.
6. ZNH model appear capable of creating financial benefits with some designs performing better than others.
7. ZNH is able to offset emissions from energy use, and also it is arguably capable of reducing energy requirements.
8. Offsetting the GHG emissions of new construction can have a significant impact on GHG emissions.

The zero net house thus appears to offer significant environmental and economical benefits for Alberta. Systems producing energy within the ZNH framework seem capable of meeting current energy needs; eliminate the reliance on fossil fuel and offer financial benefits. The positive environmental impact, in the form of GHG offset is equally significant. A widespread implementation of ZNH would arguably reduce Alberta's GHG emissions by more than 25%.

6. Recommendations

The IPCC and Mckinsey analyses repeatedly demonstrated that efficiency is a significant energy resource that offers opportunities for addressing GHG emissions. The IPCC stated that "changes in occupant behavior, cultural patterns and consumer choice and use of technologies can result in considerable reduction in CO_2 emissions related to energy use in buildings" (2007). Guided by the IPCC principles of climate change mitigation, and the research demonstrated in this paper the author recommends that the Government of Alberta take the following steps:

1. Conduct large-scale studies that consider the inclusion of ZNH specifications into the provincial building code. Studies should consider the social, psychological, economical and environmental impact of implementing ZNH specifications.
2. Investigate a possible scheme that would transition building code incrementally and efficiently with "a broad building

retrofit program, energy labeling requirements, a renovation code, and/or requiring energy upgrades during transfer of ownership" (AEEA 2009).

Due to complexities inherent in the previous recommendations the author endorses the establishment of "an expert technical advisory committee with representation including government, municipalities, and builders to provide advice on how to maximize the effectiveness of changes to the building code" (AEEA 2009).

References

[1] Intergovernmental Panel on Climate Change, 2007. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change: summary for policymakers. Bangkok, Thailand. Available from http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-spm.pdf [online, accessed 20 April 2010].

[2] Schiller SR. Energy efficiency as a climate change mitigation strategy. In: Proceedings of the ACEEE 2008 summer study on energy efficiency in buildings. 2008. Available from http://www.schiller.com/images/Schiller_et_all_energy_efficiency-_climate_paper.pdf [online, accessed 20 April 2010].

[3] Statistics Canada, 2007. Canadian environmental sustainability indicators: socio-economic information. Available from http://www.statcan.gc.ca/pub/16-253-x/16-253-x2007000-eng.htm [online, accessed 20 April 2010].

[4] Moomaw WR. This new house: living deliberately in the 21st century. Cambridge, Massachusetts: Harvard University; 2010. Available from http://www.climate-talks.net/2010-ENVRE130/Class/RR-WK-11-set.htm [online, accessed 20 April 2010].

[5] Rosta S, ASME International Energy Conference (2006: Denver, Col.). Monitoring of a zero-energy-house. New York: ASME; 2006.

[6] Alberta Geothermal Energy Association (AGEA), 2010. Strategies. Available from http://www.agea.-ca/development-/strategies.html [online, accessed 20 April 2010].

[7] Vaughan R. No subsidy: blow for zero-carbon housing targets. Architects' Journal 2007;226(21):7. Available from Humanities International complete database.

[8] Alberta Energy Efficiency Alliance (AEEA), 2009. Energy efficiency in the provincial building code. Available from http://re.pembina.org/pub/1799 [online, accessed 20 April 2010].

[9] Natural Resources Canada (NRCan), 2007. 2007 Survey of household energy use: summery report. Available from http://oee.nrcan.gc.ca/publications/statistics/sheu-summary07/index.cfm [online, accessed 20 April 2010].

[10] Norton P, Christensen C. Performance results available from a cold climate case study for affordable zero energy homes. ASHRAE Transactions 2008;114(1):218–29.

[11] Kats, G., et al., 2003. The costs and financial benefits of green buildings: a report to California's sustainable building task force. Available from http://www.cagbc.org/resources/market_value/articles107.php [online, accessed 20 April 2010].

[12] Means Company RS. Residential cost data. Kingston, MA: R.S. Means Co.; 2006.

[13] Dewis, G., 2008. Controlling the temperature in Canadian homes. Statistics Canada. Available from http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=16-001-M2008006&lang=eng [online, accessed 20 April 2010].

[14] Natural Resources Canada (NRCan), 2010. R-2000 energy saving. Available from http://oee.nrcan-rncan.gc.ca-/residential/personal/new-homes/r-2000/energy-efficiency.cfm?attr=4#targets [online, accessed 20 April 2010].

[15] Natural Resources Canada, 2010. Personal: residential. Available from http://oee.nrcan-rncan.gc.ca/-residential/personal/new-homes/r-2000/about-r-2000.cfm?attr=4 [online, accessed 20 April 2010].

[16] Government of Canada, 2010. 3.2 Housing – R-2000: Sector Sustainability Tables. Available from http://www.sst.gc.ca/default.asp?lang=En&n=CC51BF70-1&offset=3&toc=show [online, accessed 20 April 2010].

[17] Manitoba R-2000, ND. R-2000 Frequently asked questions. Available from http://www.r2000manitoba.-com/faq_print.shtml#how [online, accessed 20 April 2010].

[18] Fantec, 2009. Product specification. Available from http://www.irawoods.com/Fantech-SHR1504-SHR-Series-Heat-Recovery-Ventilator-123-cfm-0-4-WG [online, accessed 20 April 2010].

[19] Amazon.com, 2010. Fantec. Available from http://www.amazon.com/Fantech-SHR3005R-Heat-Recovery-Ventilator/dp/B0037A5V4U/ref=sr_1_1?ie=UTF8&s=hi&qid=1271788552&sr=1-1 [online, accessed 20 April 2010].

[20] Gore A. Our choice: a plan to solve the climate crisis. Emmaus, PA: Rodale; 2009.

[21] Alberta Geothermal Energy Association (AGEA), 2004. Environmental impacts. Available from http://www.agea.ca-/technology/environmental.html [online, accessed 20 April 2010].

[22] U.S. Department of Energy: Energy Efficiency & Renewable Energy, 2008. Your home. Available from http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12670 [online, accessed 20 April 2010].

[23] Wholesale Solar, 2010. Grid tie solar power system. Available from http://www.wholesalesolar.com-/solarpowersystems/grid-tie-solar-power-system-wss-select-4620.html [online, accessed 20 April 2010].

[24] Environment Canada, 2003. Alberta weather honours. Available from http://www.on.ec.gc.ca/weather/-winners/alberta-e.html [online, accessed 20 April 2010].

[25] Wholesale Solar, 2010. Grid tie solar power system. Available from http://www.wholesalesolar.com/-solarpowersystems/grid-tie-solar-power-system-wss-select-4620.html [online, accessed 20 April 2010]/.

[26] MacKay DJC. Sustainable energy: without the hot air. Cambridge, England: University of Cambridge Press Ltd.; 2009.

[27] NASA, 2007. Surface meteorology and solar energy data set: insolation levels. Available from http://www.apricus.com/html/insolation_levels_canada.htm [online, accessed 20 April 2010].

[28] Majorowicz J, Grasby SE, Skinner WR. Estimation of shallow geothermal energy resource in Canada: heat gain and heat sink. Natural Resources Research 2009. Available from SpringerLink http://www.springerlink.com/content/92q6134u4vq41111/ [online, accessed 20 April 2010].

[29] Jessop AM, Ghomshei MM, Drury MJ. Geothermal energy in Canada. Geothermics 1991;20(5–6):369–85.

[30] Rafflo G, Mertz G, Kissock K, ASME International Solar Energy Conference (2006: Denver, Colo), ASME International Solar Energy Conference. Cost-benefit analysis of net zero energy campus residence. American Society of Mechanical Engineers; 2006.

[31] Government of Alberta: Agriculture and Rural Development, 2010. Natural gas prices: historical trends and forecast. Available from http://www1.agric.gov.ab.ca/$department/newslett.nsf/all/ghb17130 [online, accessed 05 December 2010].

[32] Government of Alberta: Energy Measurements, 2010. Natural gas. Available from http://www.energy.-alberta.ca/About_Us/1132.asp#Natural_Gas [online accessed 20 April 2010].